Steady State and Dynamic Analysis of Congested Regions using D-SMES

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Abstract

This study presented the steady state and dynamic analysis to enhance the power flow and transient enhancements through D-SMES. In this paper, congested regions are observed using the steady state analysis in PSS/E software. The test case is analyzed with worst case scenario, at that time the responses of the system with or without D-SMES are compared. It stored the energy of the existing system and damped the oscillations in the network and enhanced the system stability. In this way, the issue of congestion is mitigated by improving the transient and dynamic stability of voltage, frequency and rotor angle profiles and damped the power oscillations. It also compensated the reactive power and controlled the power factor which increased the loading capacity of transmission lines. The economic analysis is also presented which provided the most economical way to transmit power.

Keywords:

Distributed super-conducting magnetic energy storage (D-SMES), power system simulator for engineers (PSS/E)

I. Introduction

Electrical Power system is a critical infrastructure having a dominant role in every walk of life. It deals with generation, transmission and distribution of electric power. The power transmission lines in power system are like arteritis, as power carrying from generating-stations to load centers. It is the natural tendency that electric load is increasing depending upon the socioeconomic and industrial trait of a particular country. As per energy requirement of a country, additional energy sources are needed in the network. Thus, due to less availability of coal, oil and other nonrenewable energy sources, the renewable energy sources are introduced in the network. These renewable energy sources such as wind or solar energy is now becoming the emergent technologies. These sources are integrated in the existing network cause of intermittence and congestion in the transmission lines. There are several methods to tackle these issues. The most efficient and cost effective method is to install the FACTS and ESS devices in the congested location of network.

In this paper, we represented the steady state and dynamic analysis of Pakistan National Grid network in the PSS/E environment. This tool is the graphical user interface and has versatile nature in simulations. All the network is modelled and analysis are carried out which showed the critical location in the network. One of the most critical location is selected for the implementation of FACTS & ESS devices. Although, in this paper, we have focused on the distributed super conducting magnetic storage system (D-SMES) device. It is the combination of SMES with IGBTs controller to give the active and reactive power according to system need. It allows the generation integration and demand response requirements and solves the issue of intermittency by aligning the power along with grid. It provides transient stability during faults, supports the voltage and frequency at critical loads and improves the power factor and power quality.

II. Distributed Superconducting Magnetic Energy Storage System (D-SMES)

Superconductor has the zero-electrical resistance when cooled below a certain critical temperature. D-SMES provides the two significant competences of active power storage and instantaneous response. One is an energy storage device which stores energy in dc magnetic field by passing the current through a coil and gives current even after the removal of voltage source. Other is IGBTs system that detects the fluctuations in the system and provide precise stability in the system. D-SMES is mainly consisted of superconducting coil with magnet, power conditioning system, cryogenic system (formation of superconductor) and control unit. During the charging, the current flows in one direction containing positive charge across the coil to store energy. The current flows through the load containing negative charge causing of discharging phenomenon. It is used to reduce the low frequency oscillations and power quality applications. It has fastest response time, rapidly switching, efficient and reliable system.

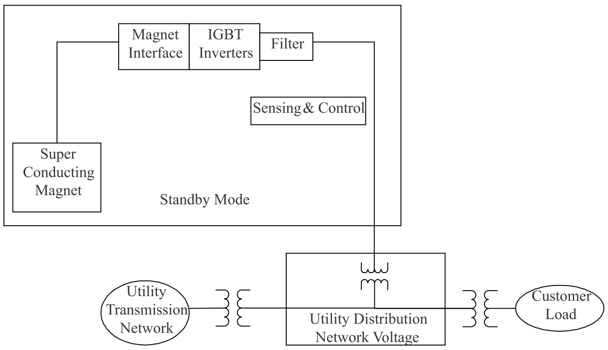

Fig 1: D-SMES

III. Power System Stability

The condition of being stable even after the disturbance in the network is the major need of the power system. The disturbance is basically due to the switching, faults and outage of the lines or equipment. These disturbances have a great impact of the voltage, frequency, and rotor angle profiles. Power system stability is mainly classified into rotor angle, frequency and voltage stability and further classified into short and long-term phenomenon.

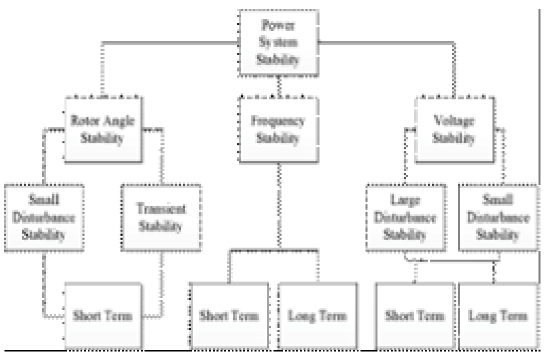

Fig 2: Power System Stability

IV. Test Case Scenario

National Grid of Pakistan is a radial network in which Northern side has Hydel power plants whereas Southern side has thermal and renewable power plants. In summer season, due to replenish of water, the hydro power plants run at their peak level. While in winter season, thermal power plants run at their maximum level. The renewable energy sources are also integrated in the network to meet the maximum demand.

We have observed that in summer season, the flow of electric power is from Northern to Southern areas whereas in winter season, the electric power flow is from southern to northern areas. Due to long radial network, the line losses are maximum in the network. It has disturbed voltage profile, reliability and stability issues so, the new lines are proposed to meet these issues. The implementation of new lines is most expensive to curtail the over loading of lines.

After the critical observation, we have observed that QESCO network is highly unstable and heavily loaded. These networks has many issues related to congestion such as voltage stability, frequency stability and angle stability. When the system of Pakistan National Grid is modelled in PSS/E then steady state analysis is studied using the Newton Raphson method. In steady state analysis, steady state performance of the system under normal (N-0) and under one-line-out (N-1) contingency conditions for on-peak and off-peak conditions for the system is observed. Circuit overloads and under/over voltages judged against the transmission design and operational criteria is highlighted to justify the need of reinforcements going to be proposed accordingly.

In accordance with the requirements of the reliability criteria, the Normal Case and N-1 Contingency Analysis is simulated throughout the system. Normal Case means when there no circuit is out of service, and Contingency means One-Circuit-Out or One-Transformer-Out as the case may be.

In Normal Case, the steady state analysis of QESCO network is studied using Newton Raphson method, which showed the critical locations of congested area. One of the critical location of congested area is Gwadar Coal PP busbar.

In given figure, QESCO network has stability issues in which current ratings are shown in boxes. The red color showed the heavily loaded branches and pink color showed the highly unstable buses.

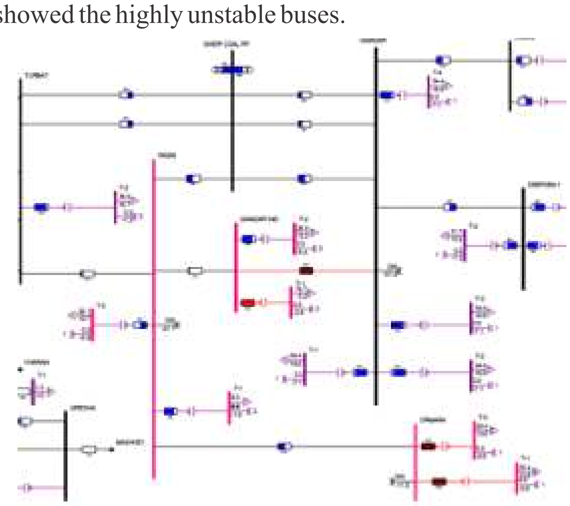

Fig 3. Loading of QESCO Network

In N-1 Contingency Case, QESCO network is more heavily loaded which is shown in pink and red color.

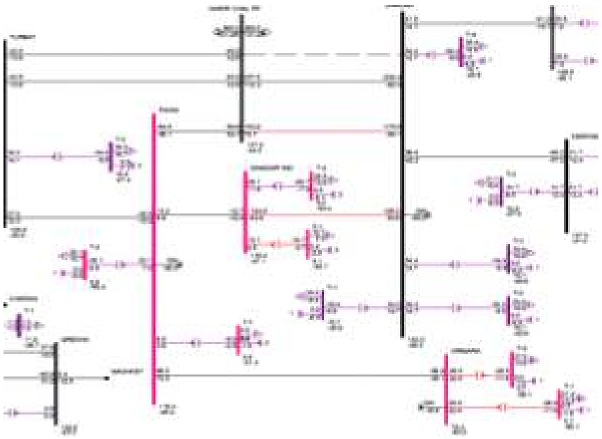

Fig 4. Loading of Congested QESCO Network

At this congested region, the stability study is carried out which showed the stability after the disturbance in the network. The stability study is investigated by following the given steps;

- Run the system for one cycle
- 3-phase (severest) bus fault is created for five cycles and then it is cleared in nine cycles
- Line is tripped from Gwadar to Gwadar Coal for twenty cycles.

The congested state under faulty situation is plotted in PSS/E by following given quantities;

1. Bus bar voltages such as Gwadar near the faulted buses
2. System frequency during and after fault conditions
3. Line power flows (MW/MVAR) through Gwadar to Gwadar Coal circuit
4. Rotor angles near the faulted transmission line, relative to the rotor angle of Tarbela

In PSS/E tool, voltage, frequency, power flows and angle waveforms are plotted against the time.

- In voltage waveform, Gwadar, Gwadar Coal PP, Pasni and Turbat are shown in red, green, blue and pink colors.
- In frequency waveform, Gwadar is shown in red color.
- In power flows waveform, the MW and MVAR of Gwadar bus bar shown in red and green colors.
- In angle waveform, Gwadar is shown in red color.

Dynamic faulty period becomes unstable and the results in the given figures showed that system voltage, frequency, line flows and rotor angle stability are not in the declared limits. Consequently the system gets unstable.

1. Voltage Waveform

At the time of fault, voltages of the bus bars are suddenly collapses and have severe oscillations unbalancing of reactive power in the system. So, it does not maintain the stable state even after the fault clearance.

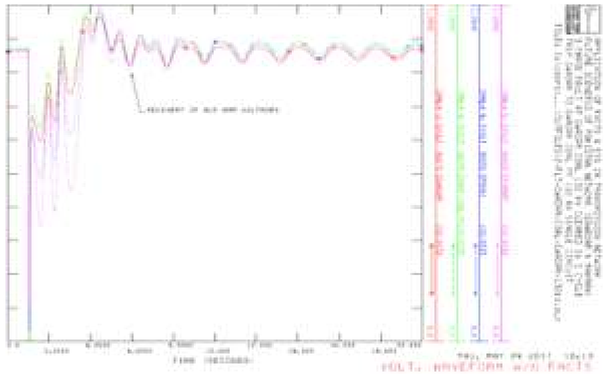

Fig 5(a): Voltage Waveform of QESCO Network

2. Frequency Waveform

At the time of fault, the frequency of Gwadar Coal bus bar has more excirsions in the system and exceed the rated limit of the frequency. It does not approach the stable state in 20 cycles after the fault clearance.

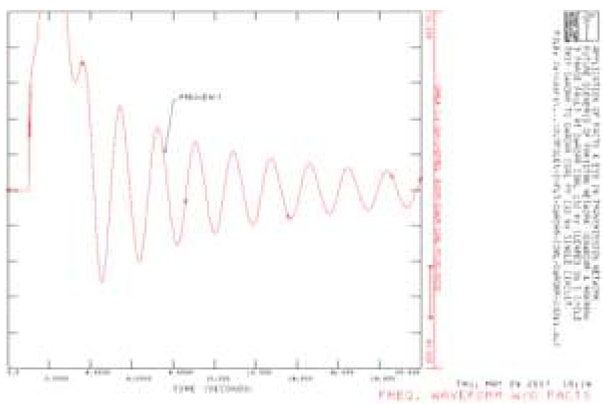

Fig 5(b): Frequency Waveform of QESCO Network

3. Power Flow Waveform

The one circuit of Gwadar to Gwadar Coal is switched thus the flow is carried out from the another circuit that is parallel to it. At the time of fault, the MW flow is drops out and its oscillation remains after the recovery of the system whereas the MVAR flow reaches its peak value and does not approach the stable state within the 20 cycles.

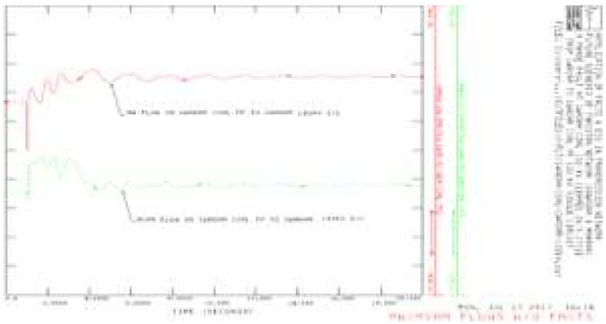

Fig 5(c): Power Flow Waveform of QESCO Network

4. Angle Waveform

At the time of fault, rotor angle reaches its maximum peak due to loss in synchronism caused by unbalancing between electromagnetic torque and mechanical torque.It does not approach the stable state even after the fault clearance.

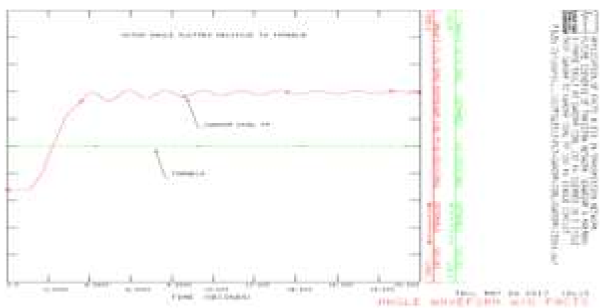

Fig 5(d): Angle Waveform of QESCO Network

These figures showed that at the time of 3-phase fault, the system voltage, frequency and rotor angle of the generator suddenly collapse too much and does not maintain their values even after the disturbance. As we have seen that congestion includes MW loading and MVAR loading. The traditional solution to MW loading is the installation of a new circuit while the solution to MVAR loading is usually installation of capacitors. However, these are not feasible or reliable solutions due to either high cost (in case of stringing new circuits) or due to nonexistent support during fault conditions (in case adding capacitors).

In the selected critical region, Gwadar is located in a remote region as far as the electrical network is concerned. There is no local generation, so it needs to draw power from the National Grid, which passes hundreds of kilometers away from Gwadar. The long transmission lines needed to transport this power need to carry high amounts of reactive power, which causes significant MVAR loading in the network. Again, the traditional solution to this scenario is the addition of transmission lines. However, this is an expensive solution, especially since hundreds of kilometers worth of transmission towers, insulators and conductors are involved. So, D-SMES is proposed for providing MWs and MVARs in the system.

V. D-SMES Modeling in PSS/E

D-SMES is the combination of SMES with IGBTs controller. It provides fast and effective control by injecting both active and reactive powers in the system. It has benefits in generation, transmission and distribution systems by improving the voltage, angular and frequency stability, damping oscillations and transmission capacity of existing system.

CDSMS1 model of D-SMES is used in this system. It is installed on 132 kV bus bar having rating of 100 MW. It provided the initial coil current of 1.05 kA and thus maintained at 0.4 kA. The magnet discharge time is 0.6 seconds which is represented in graphs. It indicated that uninterrupted and repetitive discharge according to need of system.

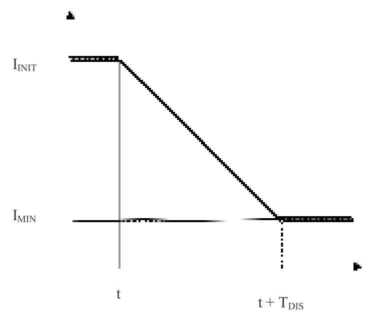

Fig 6(a) Uninterrupted Discharge

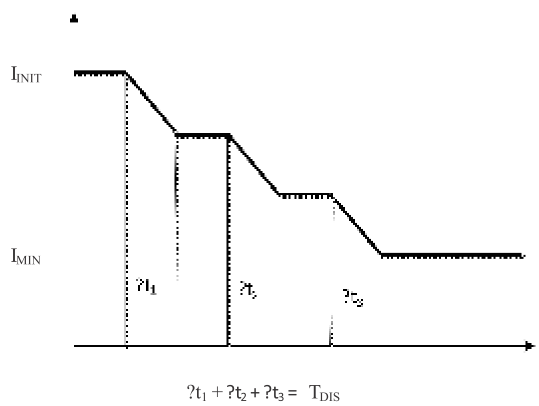

Fig 6(b): Repetitive Discharge

It injects and consumes both active and reactive power to control the voltage up to desired value in the network. It injects active power in the system by discharging the D-SMES while the reactive power injects by the IGBTs voltage source convertor.

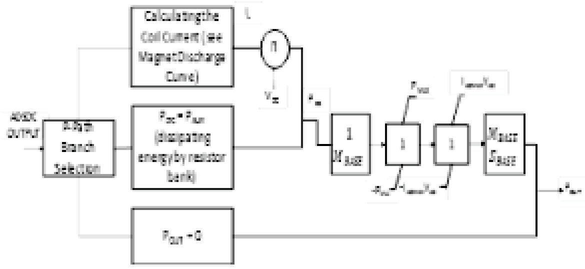

Fig 7(a): Control Diagram of D-SMES (MW Output)

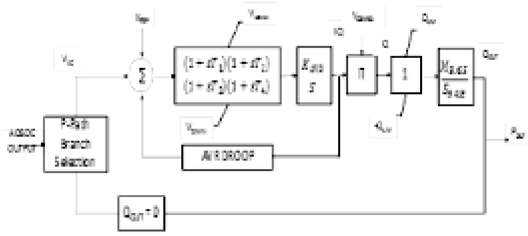

Fig 7(b): Control Diagram of D-SMES (MVAR Output)

When D-SMES is modeled in the QESCO network, the stability and quality of the system is improved which is shown in given figure.

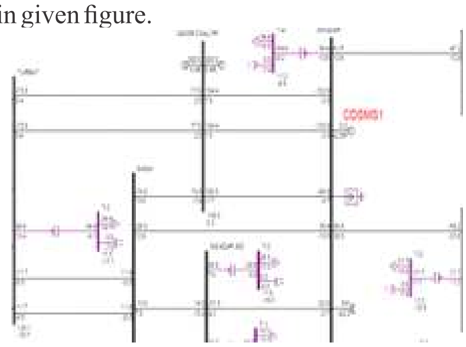

Fig 8: SLD of QESCO Network with D-SMES

These stabilities are further studied by the voltage, frequency, angle and power flow graphs.

1. Voltage Waveform with D-SMES

The voltage waveforms of nearby buses of Gwadar Coal bus bar are collapses at the time of fault. With the installation of D-SMES, the voltages of the bus bars are recovered after the fault clearance within the 6 cycles.

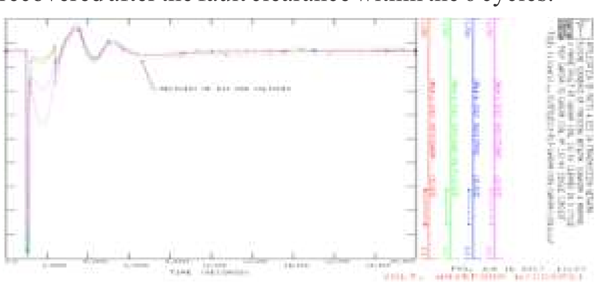

Fig 9(a): Volatge Waveform of QESCO Network

2. Frequency Waveform with D-SMES

With the installation of D-SMES, the frequency of Gwadar Coal bus bar reaches its maximum value but within its range of plot area at the time of fault due to restoration between generation and load in the network. After the fault clearance, it maintained the stable state after some oscillations within the 5 cycles.

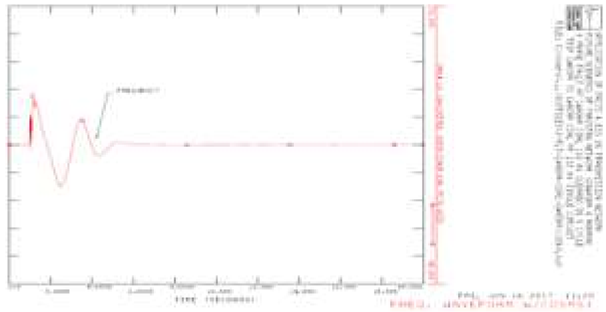

Fig 9(b): Frequency Waveform of QESCO Network

3. Power Flow Waveform with D-SMES

At the time of fault, the MW flow is drops out and its oscillation remains for 4 cycles whereas the MVAR flow reaches its peak value and approached the stable state within the 4 cycles.

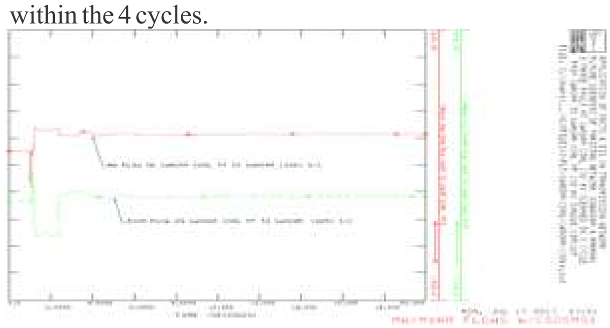

Fig 9(c): Power Flow Waveform of QESCO Network

4. Angle Waveform with D-SMES

With the installation of D-SMES, the first swing has value within the limit of plot area due to synchronism between electromagnetic and mechanical torques. After the fault clearance, the system attained the stable state within the 6 cycles.

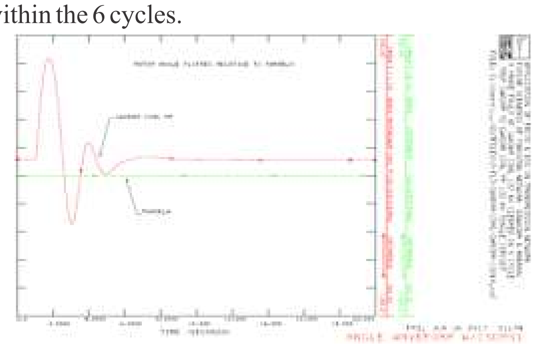

Fig 9(d): Angle Waveform of QESCO Network

5. Output Current Waveform with D-SMES

D-SMES provides the current when the sytem stability drops due to fault occurrence. After the fault clearance, D-SMES gives current untill the system achieved its stable state.

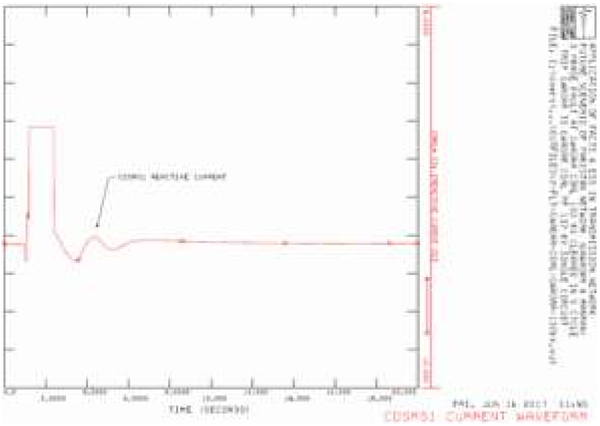

Fig 9(e): Output Waveform of QESCO Network

The dynamic stability of the network is shown by the figures of voltage recovery, frequency and angle in which they are recovered within the 10 cycles. The load flow graph showed that MW flow increases and MVAR flow decreases on the time of disturbance. The reactive output current graph showed the reactive current of the system that provides at first swing and improves the system. The output MW graph showed that CDSMS1 provides MW at the time of disturbance for transient stability.

VI. Economic Analysis

As the new line is needed for relieving the issue of congestion. It could be very expensive due to material and installation cost of tower, conductor, overhead lines, insulator strings and spacers. It also includes the right of way, line bay, civil, engineering and commissioning costs for laying the transmission lines in the network. When we calculate these costs for new transmission line, it reaches to billions. Thus by evaluating the cost of D-SMES and new transmission lines, it has a huge difference which will be pay-backed to Pakistan Nation Grid within month.

Conclusions

The issue of congestion in transmission lines is observed due to voltage, thermal limits, generation integration and load demand. It mainly deals with the active and reactive powers loadings in the lines which disturbed the voltage, frequency and rotor angle profiles. For this purpose, Pakistan National Grid is modelled in PSS/E environment in which steady state analysis showed the critical congested regions of the system. The most critical region QESCO is selected which is highly congested. In this paper, D-SMES is introduced in the congested network for mitigating the congestion issue in QESCO. It provides the active and reactive power support to the system and increases the reliability of existing system. In this way, the capability of transmission lines are enhanced and also provide the cost-effective solution.

References

[1] PSS/E 33.5 Model Library, Siemens Power Technologies International, October 2013.

[2] PSS/E 33.5 Application Program Interface, Siemens Power Technologies International, October 2013.

[3] PSS/E 33.5 Program Applications Guide, Siemens Power Technologies International, vol. 2, October 2013,

[4] PSS/E 33.5 Program Operation Manual, Siemens Power Technologies International, October 2013.